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ANALYSIS OF AVAILABLE LIFE CYCLE COST MODELS AND ACTIONS REQUIRED TO INCREASE FUTURE MODEL APPLICATIONS

Dwight E. Collins

Joint AFSC/AFLC Commanders' Working Group on Life Cycle Cost
Wright-Patterson Air Force Base, Ohio

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JOINT AFSC/AFLC COMMANDERS' WORKING GROUP ON
LIFE CYCLE COST
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This report presents the results of an effort to survey existing life cycle cost (LCC) models and to gain insight into what actions are needed to increase their use. Eight categories of LCC models are defined: accounting models, economic analysis models, cost estimating relationship models, reliability improvement cost models, level of repair analysis models, maintenance manpower planning models, inventory management models, and warranty models. The report includes an analysis of experience to date, deficiencies and potential applications of representative models within each category.

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FOREWORD

Some have suggested that one or a small number of ideal life cycle cost (LCC) models developed by a select group of specialists would provide the analysis methods needed to address most or all Air Force life cycle cost problems. However, quite the reverse may be true. This report addresses this issue. It includes a discussion of a review of currently available life cycle cost models. It also includes a discussion of actions required to further expand the application of life cycle cost analysis to a wide range of acquisition decision issues.

The author wishes to acknowledge the cooperation and assistance of many persons associated with the development or use of the models described in this report. Appreciation is also expressed to Mr. John Gibson and Capt Steven Thompson of the LCC Working Group for their support during the compilation of the report.

The Joint AFSC/AFLC Commanders' Working Group on Life Cycle Cost is attempting to continually keep abreast of new life cycle cost models and methods in order to facilitate the increased application of life cycle cost analysis throughout the Air Force. It is, therefore, requested that reports or other descriptions of new LCC analysis methods be forwarded to the Working Group Office for review and retention in the Life Cycle Cost Library. (ASD/ACL, Wright-Patterson Air Force Base, Ohio 45433)

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I. INTRODUCTION

Background

There has been considerable concern within the Department of Defense for some time about the high cost of defense systems and the rapidly increasing cost of supporting systems after they are placed into operation. The cost of operating and supporting defense systems over their useful life is generally greater than, and often several times greater than, the initial acquisition price. The Air Force life cycle costing (LCC) program is designed to bring about reduction in system and equipment operating and support costs, primarily through increased consideration and analysis of the operating and support implications of design alternatives. One important way to achieve these cost reductions is through more extensive and effective use of life cycle cost models. To achieve this goal, cost analysis and program personnel must first gain a greater awareness of the scope and adequacy of currently available models.

The term life cycle cost model, as used in this report, includes a diverse spectrum of mathematical models which can be used either to make system or equipment life cycle cost estimates or to aid in making hardware and support system design and other program decisions affecting life cycle costs. There currently exists a wide spectrum of life cycle cost models, most of which have unique and valuable characteristics for assessing specific types of life cycle cost issues.

Purpose

The primary purpose of this literature review is to answer three questions with respect to the availability of models for life cycle cost analyses in the Air Force:

1. What types of models are available?

2. To what extent are these models deficient in meeting life cycle cost analysis needs?

3. How can some of these deficiencies be overcome?

A secondary purpose of this review is to categorize existing life cycle cost models by use and to provide a brief description of one or more models in each category. The goal here is to give the reader greater insight into the nature of the various model categories and to report on experience to date in using specific models.

Scope of Study

Those characteristics of a digital computer which most significantly affect costs are generally not the same characteristics that would affect costs of an airborne electronic countermeasures package. The same holds true for a simulator or a UHF radio. In short, almost every system/subsystem/component has certain unique characteristics (design, performance, etc.) that influence its development, acquisition and operating and support costs. Because these characteristics vary widely and because of the different decision issues that occur throughout the life cycle of a system/subsystem/component, new life cycle cost models are being developed at a rapid rate. Therefore, it was not practical to review

all life cycle cost models either in existence or under development. Thus the approach taken in this review was

1. To examine a set of representative life cycle cost models.

2. To provide answers to the three questions above based primarily on our study of these models.

3. To present the representative model descriptions in a manner that (a) will make program managers aware of the capabilities of current life cycle cost analysis methods, and (b) will assist program personnel in selecting the life cycle cost models that are appropriate for analysis of the life cycle cost issues associated with their program.

Report Format

Section II of this report is a brief summary of study findings, i.e., it summarizes answers to the three questions. Sections III and IV are discussions of these findings. Section III is divided into two parts: the first part establishes a set of categories for life cycle cost models while the second part discusses some recognized deficiencies. The appendix discusses each category . more detail and describes those models in each category that were examined in the study. Again, the set of models examined is not exhaustive; rather it is considered representative of currently available modeling techniques. A bibliography of life cycle cost-related literature has also been provided.

II. SUMMARY OF FINDINGS

This review and analysis of available life cycle cost models yielded five important findings:

1. The use of life cycle cost models can provide valuable guidance for a wide range of program decision issues. There currently exist several examples where the use of a life cycle cost model has had an impact on program decisions.

2. In order for a model to be useful for analysis of a specific decision issue, it must be oriented to a narrow range of decision issues and equipment types and its input data requirements must be relatively easy to fulfill. Therefore, general purpose life cycle cost models tend to be inadequate for specific applications because they (a) lack resolution with respect to specific decision issues, (b) do not reflect characteristics of peculiar equipment types, and (c) require data in formats that are too extensive or are not compatible with formats of available data.

3. Many more models are needed if life cycle cost is to have an impact on the total spectrum of decision issues and equipment types. In particular, there is a critical need for models relating performance and design characteristics to operating and support costs. There are currently few models of this nature in existence. The development of such models can lead to reduced life cycle costs by providing a means for explicit consideration of operating and support costs during weapon system concept and design studies.

4. System and equipment specialists must become involved in structuring and using life cycle cost models in order to assure that models adequately reflect individual design and performance characteristics and are used in making important design decisions. Program personnel must also become involved in the use of models to assure that they adequately address the life cycle cost implications of decision issues associated with their programs.

5. Assistance must be provided to system and equipment specialists and program personnel if they are to increase their effective use of life cycle cost models.

III. ANALYSIS OF AVAILABLE LIFE CYCLE COST MODELS

Types of Available Models

This literature search revealed that there are numerous models available for addressing decision issues that affect life cycle cost. Some life cycle cost models have been developed to be used as general purpose analytical tools while others have been developed to meet specific program or analysis needs. Some models have been designed for application to a weapons system while others have been designed for specific types of subsystems/equipment (e.g., avionics). Some models have deterministic inputs while other have probabilistic inputs. Therefore, in order to gain better insight into the various attributes of different life cycle cost models, the Life Cycle Cost Working Group defined eight separate categories of models based primarily on the type of use for which each model was initially designed. These eight categories are:

1. Accounting Model - A set of equations which are used to aggregate components of support costs, including costs of manpower and material, to a total or subtotal of life cycle costs.

2. Economic Analysis Model - A model characterized by consideration of the time value of money, specific program schedules and the question of investing money in the near future to reduce costs in the more distant future.

3. Cost Estimating Relationship Model - An equation relating life cycle cost or some portion thereof directly to parameters that

describe the design, performance, or operating environment of a system.

4. Reliability Improvement Cost Model - An equation that reflects the cost associated with improving equipment reliability.

5. Level of Repair Analysis Model - A model that, for a given piece of equipment, determines a minimum cost maintenance policy from among a set of policy options that typically include discard at failure, repair at base, and repair at depot.

6. Maintenance Manpower Planning Model - A model that evaluates the cost impact of alternative maintenance manpower requirements or the effects of alternative equipment designs on maintenance manpower requirements.

7. Inventory Management Model - A model that determines, for a given system, a set of spare part stock levels that is optimal in that it minimizes system spares costs or minimizes the Not Operationally Ready Supply (NORS) rate of the system.

8. Warranty Model - A model that assesses the relative costs of having the Government do in-house maintenance versus having this maintenance performed by contractors under warranty.

A more detailed description of these eight categories is given in the appendix. Representative currently available models in each category and experience to date in implementing these models are also described.

Deficiencies of Available Models

This study indicated that there are four deficiencies that are commonly found in currently available life cycle cost models:

1. They are not sensitive to performance and design parameters.

2. They are too complex.

3. Their requirements for input data frequently cannot be fulfilled.

4. They are not sensitive to wear-induced failures.

These deficiencies are described in detail in the remainder of this section.

1. Model Sensitivity to Performance and Design Issues - The most well known type of life cycle cost model is the accounting model. Most accounting models compute operating and support (O&S) costs as a function of reliability and maintainability characteristics such as mean time between failure (MTBF) and maintenance manhours per operating hour. They do not relate O&S costs to system or equipment performance and design parameters such as material type, dimensions, speed, and range. This lack of model sensitivity to performance and design parameters is of particular concern since most conceptual planning and design trade studies evaluate alternative values for these parameters.

2. Model Complexity - The use of many life cycle cost models and particularly those of a general purpose nature (i.e., applicable to more than one specific equipment or decision issue) is severely limited because of model complexity. Two types of complexity are common:

a. Some of the models involve large numbers of parameters. The reason for this is often the model builder's desire to be comprehensive in his treatment of costs. Unfortunately, the effect of this type of complexity is to obscure the typically small set of parameters that have a pivotal impact on life cycle cost. As a result, the model user may spend considerable time calculating estimates of parameters that have a very small impact on cost, when in fact, he should be spending this time getting better estimates of the more critical parameters. Clearly, complexity in the sense of large numbers of parameters implies extensive data requirements. The data issue will be discussed in a later paragraph.

b. Definitions of parameters used in some models are unclear. This problem is found particularly in general purpose models. It is typically due to the fact that the model builder has had to minimize the descriptive content in his definitions in order to maintain the general purpose nature of the model. This lack of clear definitions is one reason why general purpose life cycle cost models are not used more frequently.

3. Input Data Requirements that Are Difficult to Fulfill - The inability to gather required input data for life cycle cost models is frequently the reason why these models don't get used. Two types of data problems are common:

a. Models require extensive input data. In order for the model user to have confidence in the results of model computations, he must be able to ensure that model input data is valid. This often

calls for careful scrutiny of each input data value. As the number of pieces of required input data for the model increases, the task of validating the data may become very time consuming. In many cases, this time may not be available, e.g., when several contractors submit several thousand elements of model input data as part of a bid proposal and Government analysts have a very limited amount of time in which to validate this data due to source selection schedule constraints. In such cases, model results cannot be relied on and, as a result, have very little impact on decisions. The tendency toward large input data requirements is due again to the model builder's desire for an all-inclusive cost structure so that his model might be applicable to many decision issues and many equipment types.

b. Required input data is not compatible with available historical data. Currently, it is generally recognized that the most feasible approach to forecasting field operating and support costs of new Air Force equipment is to estimate these costs based on field experience of similar equipment in the inventory. However, the process of extrapolating historical data to new equipment is generally not easy and certainly not precise. One problem frequently encountered here is inconsistencies in definitions between available historical data elements and corresponding input data elements called for by currently available life cycle cost models. Other extrapolation problems exist. For example, maintenance data is generally collected by Work Unit Code (WUC). However, there is no standardization

of assigned WUC below the subsystem (two-digit) level. In addition, component repair costs at the depot level are not identified by aircraft if the component is common to more than one aircraft.*

4. Lack of Sensitivity to Long Term Wear-Induced Failures - Most life cycle cost models that compute support costs use a parameter such as MTBF to describe reliability. The MTBF is typically used to calculate the number of failures per year which, in turn, is used to compute repair cost per year. This annual repair cost is then converted into total repair cost by multiplying by the expected number of years of operation. These computations essentially assume that failures occur at random and that the number of failures is proportional to the number of hours of total force operation.

While this assumption is valid for some devices such as electronics, it is not for devices that are subject to long term

* Although this literature review is primarily concerned with available models, it should be pointed out that much is being done in the area of data collection improvement. DoD has recognized the problem of not being able to account for support costs by weapon system/subsystem and the resulting problems encountered when extrapolating costs of these systems/subsystems in the field to new procurements. In January 1974, a task group on "Visibility and Management of Support Costs" was chartered by the Deputy Secretary of Defense to develop a system to identify maintenance and operations costs by weapon system. Additionally, the DCS/Systems and Logistics, Hq USAF, has developed a Base Maintenance Collection System which is intended to tie together local procurement costs, supply costs, and base maintenance costs (among others) to the mission/design/series (MDS) at the base level. This system is scheduled for implementation in July 1975. Also, there are other efforts under way in the Air Force Logistics Command (AFLC) to (1) allocate component and engine depot repair costs to the MDS; (2) examine procurement appropriation costs to determine the feasibility of identifying more of these costs to weapon/support systems; and (3) match operations and maintenance resources now identified to AFLC organizations with weapon/support systems.

wear-induced failures. If the wear-induced failure can be predicted, the cost associated with the failure can be estimated. In cases of this nature, preventive maintenance is generally used to avert the failure. Depot overhaul of engines is an example of this type of maintenance. However, in cases where the frequency of wear-induced failures cannot easily be predicted, e.g., the occurrence of failures due to aircraft structural fatigue, the costs related to these failures are typically ignored by existing life cycle cost models. Hence, in cases where depot overhaul due to airframe fatigue problems may be significant, most existing life cycle cost estimating models will produce an unrealistically low estimate. Moreover, since the models ignore wear-related failures, they cannot be used to determine the impact of alternative designs on costs resulting from such failures. Clearly, the problem of developing relationships that reflect long term wear-related support costs as a function of performance and design parameters is significant and deserves more attention.

IV. DISCUSSION: INCREASING THE USE OF LIFE CYCLE COST MODELS

Overcoming Model Deficiencies

There is a critical need to reduce Air Force system and equipment life cycle costs. An important aspect of reducing costs can be the increased application of life cycle cost analysis through expanded use of life cycle cost models in arriving at system and equipment planning and acquisition decisions. Correction of model deficiencies described in Section III must be undertaken to increase the effective use of life cycle cost models. Two important steps that must be taken in order to overcome current model deficiencies are discussed below.

The Air Force must begin to develop models that explicitly reflect operating and support costs as a function of alternatives considered during early weapon system concept and preliminary design planning. Models of this nature will enable Air Force planners to examine the impact of alternative weapon system concepts and designs on operating and support costs.

Life cycle cost model complexity must be reduced and model input data requirements must be made easier to fulfill. One way to achieve this is by tailoring models to specific equipment types and specific design issues. This will tend to (1) reduce the number of required model parameters, (2) increase the clarity of parameter definitions, and (3) decrease the amount of required model input data. An effort must also be made to make the required input data more compatible with available historical data. This calls for model builders to

become more familiar with the definitions, peculiarities and weaknesses of available field maintenance data products. In particular, they should know which costs are captured directly and which costs are determined by allocation procedures. They must then make special efforts to design models with these factors in mind.

The need to tailor life cycle cost models to specific decisions and to simplify them, must result in the development of many more models. This becomes even more evident when one considers the total spectrum of planning and acquisition decisions and wide variety of system and equipment types for which life cycle cost analysis is needed to derive decision guidance.

Role of Program Personnel and Specialists in Model Development

Historically, the Air Force has approached the use of life cycle cost models by establishing a few core groups with life cycle cost analysis expertise and having these experts apply life cycle cost analysis to a few selected acquisition programs. However, this approach has been inefficient because life cycle cost analysts have had to spend large amounts of time learning about unique aspects of the system or equipment and its acquisition program before they could effectively develop life cycle cost models that adequately reflected the selected program and equipment attributes. This approach was also inefficient because there are relatively few life cycle cost experts available. Even a much larger number could not adequately conduct life cycle cost analysis on all Air Force acquisition programs to which it should be applied.

An alternative to this approach exists which should be more efficient. Acquisition program office personnel can become familiar with life cycle cost analysis and model development techniques. They then could develop or adapt life cycle cost models for their own programs. This approach should be more efficient because many of the equipment attributes that are examined in life cycle cost studies are also examined in reliability, maintainability, and logistics support studies, studies that are already the responsibility of program office personnel.

There are two important initial steps in this alternative approach. First, program personnel must be assisted in becoming more familiar with life cycle cost analysis objectives and procedures. This is addressed in the next section. The second important initial step is that equipment specialists and program personnel must gain greater insight into how design and performance parameters affect the life cycle costs resulting from their individual programs.

Steps to Establishing a More Effective Life Cycle Cost Analysis Capability

If program offices are to conduct life cycle cost analysis studies to derive decision guidance for their own programs, they must be given immediate assistance to assure that this becomes standard practice in the near future. At least five actions are required in order to establish an adequately effective life cycle cost analysis capability in acquisition program offices.

1. Program offices must be provided with a source of personnel familiar with analytical techniques. In many cases, expertise already

exists in the form of available engineers, operations research, and cost analysts that support these offices.

2. These engineers and analysts must be given general guidance on how to develop, adapt and use life cycle cost models for specific applications. This guidance need not be detailed, but should clearly convey the objectives of life cycle cost analysis with respect to arriving at program decisions.

3. Program office and supporting personnel should have access to a short course in the subject of development and application of life cycle cost models and methods. Action was underway in late 1974 to establish such a course at the AFIT School of Systems and Logistics.

4. Periodic life cycle cost methods workshops should be held so that lessons learned by certain program offices in LCC model development, modification, and application can be conveyed to other program offices having similar life cycle cost objectives.

5. Finally, program office personnel should be provided with a central focus of expertise where lessons learned in each new life cycle cost application are integrated with existing life cycle cost models and methods, and where program personnel can gain additional guidance when unique problems arise. At present, two such cores of expertise are the Deputy for Acquisition Logistics, Hq AFLC, and the Joint AFSC/AFLC Commanders' Working Group on Life Cycle Cost. Similar expertise is being developed at the AFLC Air Logistics Centers and the AFSC Product Divisions.

High and continually increasing life cycle cost demands that everything possible be done to reduce these costs. Consideration of life cycle costs in arriving at all system and equipment program decisions is an important action that can be taken in the efforts to reduce life cycle cost. It is a large undertaking to expect life cycle cost to be considered with respect to the many decisions that face all new Air Force programs. On the other hand, economics has always been an integral part of engineering and management. Therefore, consideration of life cycle costs in planning, design, source selection, warranty and other decisions is not a new concept. It is the placing of increased emphasis on a current and critical Air Force problem.

APPENDIX

DESCRIPTION OF REPRESENTATIVE AVAILABLE LIFE CYCLE COST MODELS

I. ACCOUNTING MODELS

The most familiar category of LCC models in the literature today is the accounting model, i.e., a model that computes the operating and support portion of LCC of a weapon system or subsystem as a function of logistics parameters. This type of model is characterized by computations for such cost categories as spares and maintenance, which may initially be computed at relatively low levels of indenture, for example, for individual Line Replaceable Units (LRUs). The model primarily sums these different costs for each LRU as well as other cost categories, hence the generic classification accounting model.

A. THE AFLC LOGISTICS SUPPORT COST MODEL*

Objective of Model: The objective of the AFLC Logistics Support Cost (LSC) model is to estimate the support costs that may be incurred by adopting a particular design for a given weapons system or piece of equipment. "The model is intended for application in two areas: (1) to obtain an estimate of the differential logistics support costs between the proposed design configurations of two or more contractors during source selection; and (2) to serve as a decision aid when discriminating among design alternatives during prototyping for full-scale development."

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* Taken from "Logistics Support Cost (LSC) Model User's Handbook," AFLC/MMOAA, Wright-Patterson AFB, Ohio 45433 (February 1974). (MMOAA has since been realigned with the AFLC Deputy for Acquisition Logistics; office symbol is currently AQMLE.)

Model Description: The model computes an estimate of logistics support cost as a function of five categories of data elements:

1. Program elements, i.e., data characterizing flying hour programs, deployment and operating scenarios, etc., that are furnished by the Government.

2. Contractor-furnished subsystem elements, i.e., estimates of costs such as cost of special depot facilities that are not directly associated with line replaceable units (LRUs) but nonetheless contribute significantly to overall system cost.

3. Propulsion subsystem elements, i.e., for those defense systems that include propulsion systems, data such as mean engine operating time between removals (contractor-furnished) and engine repair cycle time at base and depot levels (Government-furnished).

4. Contractor-furnished LRU elements, i.e., estimates of parameters such as mean flying time between maintenance action (MFTBMA) that are based on characteristics of the design of the LRU.

5. Government-furnished standard elements, i.e., elements such as labor rates, inventory costs, and repair cycle times.

The LSC model consists of ten equations or submodels, each of which represents a component of the total cost of resources necessary to operate the logistics system. The ten cost components are:

1. Initial and replenishment LRU spares cost.
2. On-equipment maintenance cost.
3. Off-equipment maintenance cost.
4. Inventory entry and supply management cost.

5. Support equipment cost.

6. Cost of personnel training and training equipment.

7. Cost of management and technical data.

8. Facilities cost.

9. Fuel consumption cost.

10. Cost of spare engines.

The first seven of these cost components is evaluated for each appropriate LRU and the results are aggregated over all subsystems. To arrive at a logistics support cost for the total system, the last three components are added.

Examples of Model Use and Prospects for More Extensive Use: To date the LSC model has been used by several program offices as a vehicle for considering LCC trade-offs and for estimating logistics support costs. Some examples of its use are:

1. It was used to compute a support resources estimate that was used as a primary source selection criterion in selecting the B-1 electronic countermeasures package.

2. It has been used to compare alternative avionics packages for the B-1 on the basis of support resource impact.

3. It is being used by the aircraft contractor for the B-1 as a vehicle for computing the effects of proposed ECPs on estimated LCC.

4. A modified version of the model will be used during the Full-Scale Development (FSD) source selection of the Air Combat Fighter to identify candidates (i.e., high consumers of support resources to be

agreed upon by the Government and the eventual FSD contractor) for either a follow-on Reliability Improvement Warranty (RIW) or a correction of deficiencies clause.

The LSC model has been found to have certain weaknesses associated with it that need to be overcome if models of this kind are to gain wider acceptance in the future. Two of these weaknesses are described below:

1. The principal weakness of the LSC model is the lack of a reliable and accurate set of historical data to estimate component costs on an analogous basis. This is due in part to the fact that the multiple data systems used by AFLC are designed for purposes other than weapon system cost accounting. For example, the base level maintenance data collection system is largely a production control monitoring and scheduling system. Because of these diverse sources of data, only partial weapon system support cost visibility is to be found at best, and a great deal of prorating of common expenses applicable to several weapon systems exists

2. A companion problem exists in the practice of managing both depot level maintenance and supply by National Stock Number (NSN), base level supply by NSN, and base level maintenance by Work Unit Code (WUC). The fact that there is no direct one-to-one mapping of NSN to WUC serves to further aggravate the data problem, especially at the component level.

The difficulty of using the LSC model to compute estimates of support resources given the above problems becomes rather apparent.

The effects on model output of uncertainties associated with the input values are further clouded as costs are aggregated. Thus, when the LSC model is used as a source selection tool prior to the validation phase studies, i.e., at a time when input parameter estimates required to implement it are particularly uncertain, the resulting estimate should be exposed to a wide range of sensitivity analyses to isolate input values that have a critical effect on the output estimate.

B. AFLC OPERATIONS AND SUPPORT (O&S) COST MODEL

The objective of the AFLC O&S cost model are virtually the same as those of the AFLC LSC model. The two models both compute O&S cost as a function of logistics parameters. They differ in minor respects, e.g., the LSC model breaks down cost to the LRU level for AGE whereas the O&S cost model does not. The O&S cost model was used for full-scale development source selection on the A-10 Program.*

C. THE PLANNING AIRCRAFT COST ESTIMATING (PACE) MODEL

The PACE model differs substantially from the accounting models described previously. Nonetheless, it is included in the accounting model category because like the accounting models above, it has historically been used to estimate operations and support costs. The fundamental difference between the PACE model and the LSC and O&S cost model is that the PACE model does not compute operating and

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* A full description of this model is included in a report entitled "Review of the Application of Life Cycle Costing to the A-X/A-10 Program (1970-1973)," prepared by a study team under the direction of the Joint AFSC/AFLC Commanders' Working Group on Life Cycle Cost, ASD/ACL, Wright-Patterson AFB, Ohio 45433, October 1973.

support costs directly for individual subsystems and LRUs. Rather, it aggregates costs for several cost categories by using gross averages of spares, AGE, manpower, etc., that are found in various tables of AFM 173-10. These averages are given either as a function of the number of flying hours or the number of aircraft. Hence, cost estimates obtained from the PACE model are essentially based on simple extrapolations of these gross averages from similar or analogous weapon systems, and not on specific design and performance characteristics of the weapon system for which an estimate is being made.

Additionally, the PACE model includes many support costs (base operating, medical, factors for UPT/UNT training, pipelines, vehicle, etc.) which aren't considered in other life cycle cost models. Use of average historical cost factor data is indicative of the PACE model's insensitivity to design characteristics.

The PACE model has been used recently to develop an operating and support cost estimate for a Defense Systems Acquisition Review Council (DSARC III) decision on the A-10 aircraft.* It is also being used by McDonnell Douglas on contract to the F-15 Program Office for O&S cost estimates. The PACE model is the generally accepted Air Force format for preparing operating and support cost estimates for submission to the DSARC.

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* Further information on this application and details of the PACE methodology are available from Lt Col Richard Goven, AF/ACMC, The Pentagon, Washington, D.C. 20330. A description of the model appears in the USAF Cost & Planning Factors Manual (AFM 173-10 (CONFIDENTIAL)).

D. SIMPLIFIED MAINTENANCE COST MODEL*

The Joint AFSC/AFLC Commanders' Working Group on Life Cycle Cost, in conjunction with the Deputy Chief of Staff for Acquisition Logistics, Air Force Logistics Command, has requested a service test of a possible new data system designator to be generated quarterly for the purpose of running the REDUCE model (described in Appendix II, Economic Analysis Models). Additionally, it has been determined that certain data elements from this proposed product can be used to produce a gross estimate of annual maintenance costs (including special repair activity costs, pack/ship costs, condemnation costs, and, where possible, base material costs). The simplified model requires only six input data parameters:

1. Mean time between failure (MTBF), using the AFLC Panel 34 definition of failure.

2. Mean time between other-than failure-related maintenance actions (MTBMA).

3. Cost per failure.

4. Cost per non-failure-related maintenance action.

5. Quantity per application.

6. Quarterly force flying hours.

The model will compute the total annual and unit annual maintenance costs and list the maintenance costs for each component or subsystem,

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* Additional information can be obtained from ASD/ACL, Wright-Patterson AFB, Ohio 45433. When the new data system described above becomes available, a report will be prepared on both the data system and use of the simplified maintenance cost model.

from the most expensive to the least expensive. The simplified maintenance cost model has three major potential uses. First, it can be used to compare maintenance cost estimates for proposed designs with actual maintenance costs of existing designs. Such comparisons can be used for source selection evaluation guidance or any other evaluation where relative rather than absolute maintenance cost estimates are useful. The word "relative" is emphasized here because, among other reasons, there presently exists little field experience data on base material costs, one of the components of the cost per failure figure used in the model. Second, the simplified model can be used to assess the maintenance cost implications of test results and then used to track estimated maintenance costs of new equipment. Third, since the model separates those costs attributed to actual failures from those attributed to other maintenance actions, it goes one step beyond the current K051 (IROS) data system. This additional piece of information should prove useful in pinpointing whether high support costs are the result of poor reliability or non-failure-related problems.

E. OTHER ACCOUNTING MODELS

General Purpose Models: There exist numerous other general purpose accounting models in the literature that perform the same function as the AFLC LSC model but differ in minor respects in nomenclature, level of detail at which costs are isolated, etc. A list of some of the more recent models in this category appears below:

1. "Computerized Model for Life Cycle Cost Analysis," Lear Siegler Publication No. GRR-006-0474, Lear Siegler, Inc., Instrument Division, 4141 Eastern Avenue S.E., Grand Rapids, Michigan 49508, 1 April 1974.

2. "Programmed Technique for Evaluating Cost Trade-Offs (PROTECT)," prepared by K. J. Gibson, A158-D-3 Rev. 2/73, Autonetics Division, Rockwell International, 3370 Miraloma Avenue, Anaheim, California 92803.

3. "Model for Life Cycle Cost Analysis," William J. Bonner, Litton Systems, 5500 Canoga Avenue, Woodland Hills, California 91364.

Special Purpose Models: There exist several accounting models that have been developed to aid in making LCC estimates and trade-offs in specific areas, e.g., UHF radios. A list of some of the recently developed models of this nature appears below:

1. "A Life Cycle Cost Model for Inertial Navigation Systems," prepared by Thomas D. Meitzler and Russell M. Genet, Plans and Programs Office, Aerospace Guidance and Metrology Center (AGMC), Newark Air Force Station, Newark, Ohio 43055, 13 June 1974. This model was used to compare alternative inertial navigation systems for the B-1 bomber in 1972. It is currently being used by avionics engineers at the Aeronautical Systems Division (ASD/ENA) to compare not only inertial navigation systems but also other avionics equipments on the basis of life cycle cost. Most of these more recent

applications of the model have been in the context of retrofitting decisions.*

A more detailed life cycle cost model for use with respect to inertial systems and ultimately all avionics is currently under development by the Life Cycle Cost Task Group of the Joint Services Data Exchange (JSDE) Group for Inertial Systems. One of the central goals of this model is to provide a common framework for use by the three services and all inertial systems contractors when estimating life cycle cost. It should provide all participants in the inertial system procurement process with a common language for discussing life cycle costs in order that more valid comparisons and more accurate judgements might be made on the basis of life cycle cost.**

2. "Life Cycle Cost of Modular Electronic Equipment," TD-1980, November 1973, Revision 1, 8 February 1974, Naval Avionics Facility, Indianapolis, Indiana 46218. Distribution limited to U.S. Government agencies only.

3. "Life Cycle Cost Design Trade-Offs for a Developmental UHF Modular Transceiver," Norbert Schroeder and Carl Sonty, Tracor Sciences and Systems, Tracor, Inc., 1117 North 19th Street, Suite 1200, Arlington, Virginia 22209.

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* Further information on this application of the AGMC model is available from Lt Col Lee Haygood, ASD/ENA, Wright-Patterson AFB, Ohio 45433 (513/255-6755/6698).

** Further information on this life cycle cost model is available from Mr. Russell B. Stauffer, Manager, TIRAS Department, Dynamics Research Corporation, 60 Concord Street, Wilmington, Mass. 01887 (617/658-6100).

II. ECONOMIC ANALYSIS MODELS

An important function where analytical models can be put to good use in the Air Force is the determination of the economic implications of decisions to modify or augment the capabilities of current weapons systems. Retrofit decisions typically raise the issue of whether to spend funds in early years to achieve savings in later years. Mathematical models can be used to evaluate the economic implications of alternative retrofitting programs and can lead to decisions that reduce life cycle cost in the long run. The REDUCE model described below is an example of an economic analysis model.

REDUCE: AN AIRCRAFT SUBSYSTEM ECONOMIC ANALYSIS MODEL*

Objective of the Model: To serve as a tool for evaluating the USAF forcewide economic implications of proposed alternative new and retrofit aircraft equipment programs.

Description of the Model: REDUCE (Research into the Economics of Design and User Cost Effects) can be used to compute the life cycle cost implications of:

1. An aircraft retrofit program in which new equipment with different reliability and maintainability characteristics will replace presently installed equipment performing the same function, on all or selected aircraft in the Air Force inventory.

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* Cerone, James R., et al, "The REDUCE Model: Description," Caywood-Schiller Division, A. T. Kearney, Inc., July 1972; ASD/XR-72-34; prepared for Deputy for Development Planning, ASD/XR, Wright-Patterson AFB, Ohio 45433. For additional information contact ASD/ACL, WPAFB, Ohio.

2. Alternative new equipment proposals providing different equipment designs for performing additional functions on existing aircraft or specific functions on new aircraft.

3. Changes in operating and maintenance policies.

When comparing the relative economic merits of alternative designs for a proposed new equipment item, the model considers estimates of RDT&E, acquisition/installation, and maintenance costs over the full life of the system. In the case of a retrofit program, the model produces comparisons between the life cycle costs of a proposed new item and the support costs of the items it would replace. It also provides the capability for exploring tradeoffs between the investment of money in RDT&E to improve an item's reliability and maintainability characteristics and consequent savings in maintenance costs during the item's operating lifetime. The model uses discounting procedures to calculate the present values of future program costs and also has the capability to consider inflation and estimate out year costs in then-year dollars. The model provides a variety of output formats designed for both budget and decision analysts.

The model is composed of the following major components:

1. A data base needed to describe the scope of future operations; the equipment configuration of each aircraft series to be considered for retrofit; and reliability, maintainability, and cost factors of equipment items currently installed in these aircraft.

2. The INIT module which establishes a data base in a computer storage-compatible format initially and updates the data base after it has been established.

3. The ACOUT module which produces output formats containing information required to make decisions concerning item replacement.

4. The SETUP module which transforms inputs on a proposed new item into computer records that can be operated on by other modules.

5. The RETROFIT module which evaluates the life cycle cost effects of proposed retrofit programs.

6. The NEW vs NEW module which computes and compares the life cycle costs of several alternative new items being considered for performing a given function.

Potential Model Applications: The model requires considerable input data. The effort required to obtain this data is most easily justified for a complex problem involving the possible use of a new improved piece of equipment on several aircraft types over a long period of time. It is ideally suited to economically evaluate the potential value of standardization of new and low maintenance cost subsystems throughout the Air Force.

III. COST ESTIMATING RELATIONSHIP MODELS

Statistical cost estimating relationships (CERs) are mathematical equations that express the total or specified partial cost of a system or equipment directly as a function of (1) physical properties (e.g., accuracy, volume, or parts density) of the system/equipment or (2) properties of the operating environment in which the system/equipment will be used (e.g., deployment scenario, flying hour program, or aircraft environment). They are typically derived by using statistical regression to fit cost data on existing similar systems/equipments to the data that reflect physical or environmental properties for these systems and equipments. Their advantage over accounting models is twofold: (1) They can be developed and used early in the conceptual and preliminary design stages of RDT&E to study the effects on cost of varying these properties and hence to compare alternative requirements on the basis of cost. (2) They can be used to obtain preliminary estimates of cost when details of design or operating and support concepts are not yet known.

Cost estimating relationships have frequently been used in recent years to estimate the acquisition costs of new Air Force equipments. However, there is little experience to date in the use of CERs to estimate total life cycle costs or operating and support costs. There is a great need for CERs that reflect operating and support costs as a function of design parameters and can be employed early in weapon system development. They are needed to enable decision makers to more explicitly consider the impact of alternative design

concepts on operating and support costs. Estimating relationships that predict the costs of attaining various levels of equipment reliability are also needed in order to determine equipment reliability design goals that result in reduced life cycle costs.

Few CERs dealing explicitly with life cycle cost, operating and support cost, or reliability improvement cost exist at present. The models described below represent initial efforts to derive relationships of this type.

A. RELATIONSHIPS FOR ESTIMATING LIFE CYCLE COST OF AVIONICS SYSTEMS*

Objective of the Relationship: To reflect life cycle cost as a function of avionics subsystem design parameters in order to compare subsystem design alternatives in design areas such as subsystem packaging, commonality, and over design on the basis of life cycle cost.

Description of the Relationship: A set of CERs was developed to examine the effects on avionics system life cycle cost of different design approaches to producing modularity, commonality, and standardization. The CERs estimate the costs of RDT&E, procurement, and operation and support. They incorporate production learning curves, Air Force provisioning policies, supply system management factors, and repair, replacement, and condemnation policies.

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* 1. Coult, J. R. et al, "Aircraft Avionics Tradeoff Study, Volume II: Concept Development and Tradeoff, Part II, Equipment Trandeoffs," Honeywell, Inc., USAF Tech Report ASD/XR 73-18, September 1973.

2. Crowe, R. K. et al, "Aircraft Avionics Tradeoff Study, Volume III: Concept Application, Evaluation, and Implementation," Honeywell, Inc., USAF Tech Report ASD/XR 73-18, September 1973.

Unlike several existing models for estimating life cycle cost, these CERs compute LCC as a function of a relatively small number of parameters; namely, procurement cost, production learning curve factors, MTBF, number of subsystems, number of LRUs, and flying hours per month per system. Hence, they can be used to compare the life cycle cost impact of differing design alternatives in equipment development when logistics parameters such as percent of failures repaired at depot (NRTS) and maintenance manhours per flying hour (MMH/FH) have not yet been estimated.

Prospects for Use of the Relationships: At present, the primary source of experience with these CERs is the Quick-Strike Reconnaissance Systems Analysis Study. This study was undertaken by the Design Analysis Branch of the Engineering Avionics Directorate at ASD.** Its purpose was to examine several alternative real time reconnaissance equipments in order to determine optimal mixes of equipment and optimal equipment deployment schemes. The CERs were used in this study to compare avionics equipments on the basis of life cycle cost.

** The project manager for this study is Mr. Larry Beasley, ASD/ENA, Wright-Patterson AFB, Ohio 45433.

B. RELATIONSHIPS FOR ESTIMATING OPERATING AND SUPPORT COSTS OF AVIONICS EQUIPMENT*

In this study, several cost estimating relationships (CERs) were developed for the purpose of forecasting yearly maintenance cost as a function of purchase price and certain design parameters such as mean time between failure (MTBF) and peak operating power. The study also developed factors for estimating initial spares cost and AGE and AGE spares cost as a percentage of equipment investment cost. Sources of data for the study included RADC, IDA, ARINC, and AFLC. A primary problem encountered during this effort was considerable noise in the maintenance cost data. This caused several of the resulting CERs to have lower coefficients of determination than desired. Nevertheless, annual maintenance CERs for doppler and fire control radars and bomb-nav systems exhibited adequate coefficients of determination and standard errors.

A follow-on contract is underway to develop a more comprehensive set of CERs in this area.** Particular attention will be given to more extensive use of MTBF and other design parameters as independent variables in these studies. Equipments to be considered include radar warning receivers, electronic countermeasures pods, inertial measurement units, radars, TVs, lasers, and computers.

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* Cost Analysis of Avionics Equipment, Air Force Avionics Lab (AFAL) Technical Report 73-441, February 1974. This study was done for AFAL by General Research Corporation and was directed technically by Major Richard Grimm.

** The Project Engineer for this contract is Capt Lee Darlington, AFAL/AAA-4, Wright-Patterson AFB, Ohio 45433.

C. STATISTICAL RELATIONSHIPS FOR ESTIMATING COST OF RELIABILITY PROGRAMS*

Objectives of the Relationships: (1) To provide a quantitative basis for estimating costs of reliability design programs, reliability parts programs, and reliability testing programs so that these costs can be more explicitly considered and accurately estimated when budgeting for the development of avionics equipment. (2) To provide a method for giving visibility to the costs of achieving given levels of avionics equipment reliability.

Description of the Relationships: The following types of statistical relationships were derived.

1. Total reliability program cost (in man-days) as a function of resultant equipment MTBF and number of electrical parts in the equipment.

2. Cost of reliability design program, reliability parts program, and reliability test program, each as a function of number of electrical parts.

3. Resultant equipment MTBF as a function of reliability parts program cost, reliability test program cost, and number of electrical parts.

4. Incremental increase in reliability program cost as a function of incremental increase in MTBF.

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* Reliability Acquisition Cost Study, General Electric Company, (Salvatore P. Mercurio and Clyde W. Skaggs), Contract F30602-72-C-0226, Project 5519, Job Order No. 55190256, prepared for RADC (RBRS), Griffiss AFB, New York 13441 (Contract Monitor - Mr. Jerome Klion)

The relationships were developed using data from two manufacturers on ten equipments. Both aircraft and space equipments were considered. The reliability design program was assumed to include prediction, failure modes and effects analysis, and design reviews; the parts program was assumed to include parts screening specification, parts standardization and control, and vendor control; and the reliability test program was assumed to include evaluation testing, equipment environmental screening, and reliability demonstration testing.

These relationships can be used in trade-off and life cycle cost analyses to provide a heretofore missing link, namely, a relationship between reliability development cost and resulting reliability. They can also be used to determine the optimum size and mix of reliability program elements in any development environment that is similar to the one from which data for this study was gathered.

Prospects for Use of the Relationships: To date, there has been virtually no experience in using the CERs described above in design of new reliability programs because the relationships were developed so recently. However, there are plans to use them at two levels as described below:

1. The General Electric Company plans to use the CERs to structure reliability programs and estimate reliability program costs in future avionics development efforts.

2. In its capacity as monitor of several reliability programs at ASD and ESD, RADC plans to use the CERs to estimate the costs associated with these programs and to evaluate the levels of

reliability improvement that are achievable with given levels of program funding.

In addition to these planned efforts, it is also hoped that analysts associated with SPOs will take the initiative to use the CERs in designing and budgeting for avionics reliability programs associated with their systems.

IV. RELIABILITY IMPROVEMENT COST MODELS

There is considerable evidence in the LCC literature indicating that more money spent to improve the reliability of present Air Force equipments could have resulted in far greater reductions in operating and support costs. The task of getting increased funding for reliability improvement work during the development cycle would be easier if development managers more clearly understood the relationship between equipment reliability and cost.

In recent years, several models have been developed for the purpose of explicitly identifying this relationship. Models of this kind can be very helpful in determining how much money should be budgeted to attain given levels of reliability and to determine the level of equipment reliability that minimizes life cycle costs.

The examples below represent two efforts to quantify the reliability-cost relationships.

A. A MODEL FOR EVALUATING WEAPON SYSTEM RELIABILITY, AVAILABILITY AND COSTS*

Objective of Model: To reflect the relationships among system and subsystem reliability and availability design requirements and life cycle costs in order to provide a basis for making cost effective trade-off analyses to determine the optimum reliability and availability requirements for a system and its component subsystems.

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* "Criteria for Evaluating Weapon System Reliability, Availability, and Costs," Task 73-11, March 1974, Logistics Management Institute, 4701 Sangamore Road, Washington, D.C. 20016.

Model Description: The model is constructed to determine the optimum reliability for each of any number of subsystems which comprise a specific system, such that the total life cycle cost of the system, as affected by reliability is a minimum. Three principle types of cost are considered in the model:

1. Cost of system downtime resulting from imperfect reliability. As reliability of a given subsystem decreases, downtime of the aircraft on which the subsystem is located tends to increase so that additional aircraft are needed to meet a given mission requirement. Downtime cost is defined in terms of the life cycle cost of these additional aircraft.

2. Design, development, acquisition and program management costs associated with achieving given levels of reliability. A reliability growth model developed by J. T. Duane of the General Electric Company is used to reflect these costs.

3. Maintenance and support costs associated with system, subsystem, and component reliability. The approach used here is to identify, from total maintenance costs reported or estimated, that portion which is recoverable, i.e., the cost that would not be expended if a failure did not occur. This recoverable cost therefore comprises the component of maintenance and support cost that varies with subsystem reliability.

Examples of Model Use and Prospects for More Extensive Use: The model was used in conducting case studies of the F-4C, F-105D, B-52H, and C-141A aircraft systems. The purpose of the studies was to

evaluate the life cycle cost savings achievable if, at the time of system development, the optimum subsystem reliability had been determined and achieved through a reliability growth program. Input data for the model was gleaned from AFLC systems G033B, DO56, D165A, K051, Project ABLE, and Project IROS. For each aircraft system, the model was exercised to determine the optimum MTBF for each major subsystem, the resultant MTBF for the entire system, and the total life cycle cost which would have been incurred if optimum MTBFs were achieved. The present MTBF experienced by each subsystem as found in the data was used to determine the life cycle cost under current MTBF conditions. The studies indicated in all four cases that there could have been significant reductions in life cycle cost if there had been additional investment in reliability growth during development. They also indicated that a return on this additional investment of 240 percent to 600 percent could have been realized.

The model was also used in an analysis of the AN/APQ-120 radar on the F-4E. The analysis sought to determine whether this low reliability radar should be improved via installation of higher reliability parts or replaced by a higher reliability radar, the WX-200. The study indicated that the former decision would result in a lower life cycle cost. This conclusion coincided with recommendations made by an Air Force/industry study that had been undertaken to determine a source of action with regard to this radar.

The examples above indicate that under appropriate conditions, the model can be used to produce relatively good estimates of

optimum reliability levels. Efforts should be undertaken to prove the usefulness of this modeling approach in more Air Force reliability programs.

B. A MODEL FOR TRADING OFF SYSTEM RELIABILITY PERFORMANCE AND COST*

Objective of the Model: Given several discrete options that vary in reliability performance (MTBF) and cost (acquisition cost or life cycle cost) for each of several subsystems of a weapon system, to find that set of subsystem MTBF options that maximizes system reliability performance (in terms of mission completion success probability (MCSP)) subject to a constraint on total cost of the system.

Description of the Model: The model (known as the "Designing to System Performance/Cost" or "DSPC" model) was developed to be implemented with respect to a weapon system consisting of a set of mission critical subsystems. For each subsystem, estimates of parameters such as acquisition cost, MTBF, and average cost per repair are required as input data. The cost by which system performance is constrained in the model may be acquisition cost or total life cycle cost.

The optimization procedure is simple and easily implemented. It yields a concave curve reflecting MSCP as a function of cost and

* Anderson, Richard H., et al, Models and Methodology for Life Cycle Cost and Test and Evaluation Analyses, OAS-TR-73-6, Section IV, Office of the Assistant for Study Support, DCS/Development Plans, Air Force Systems Command, Kirtland AFB, New Mexico 87117.

consisting of straight line segments that connect vertex points. The curve has the following properties:

1. Each vertex represents the maximum MCSP achievable at the associated cost.

2. No combination of subsystem options will yield a point above the curve.

3. Moving along the curve from one vertex to an adjacent vertex is equivalent to changing only one subsystem option. Hence, intermediate points on this straight line segment can be realized (on a fleet basis) by equipping only a certain fraction of the fleet with the new option.

The model can be implemented with respect to existing systems when it is desired to determine an optimal allocation of funds for the reliability improvement of one or more of the system's subsystems.

Recent Experience with the Model: The model was recently used in support of a Target Activated Munitions Program at Eglin AFB. Plans are currently underway to use the model in support of the EF-111A Program Office at Wright-Patterson AFB.**

** Further information on these efforts is available from Mr. Thomas E. Dixon, AFSC/XR/OAS, Kirtland AFB, New Mexico 87117.

V. LEVEL OF REPAIR ANALYSIS MODELS*

Another approach to reducing life cycle costs is the use of more effective and less costly maintenance or level of repair policies for Air Force weapons systems. Several mathematical models have been developed in recent years for the purpose of determining the least cost level of repair policy for new equipments as they are introduced into the Air Force inventory. Most of these models fall into one of the three categories described below.

A. SINGLE ITEM - SINGLE INDENTURE MODELS**

This type of model simply adds up the various costs of each of three maintenance alternatives for a given line replaceable unit (LRU): (a) discard at failure, (b) repair at base, (c) repair at depot, and identifies the least cost of the three policies. This type of model has some limitations:

1. It requires the use of an allocation procedure for costs of such items as support and test equipment that are used to repair more than one type of LRU. This usually results in a requirement for several iterations of the model for each LRU in order to ensure that LRUs designated for repair at a given location carry totally allocated costs.

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* Further information with respect to Level of Repair Analysis Models can be obtained from Mr. Perry Stewart, AFLC/AQMLE, Wright-Patterson AFB, Ohio 45433 (513/257-2051).

** The term "indenture" refers to the level of hardware breakdown and disassembly, e.g., system, subsystem, line replaceable unit, shop replaceable unit, module, and piece-part.

2. It does not explicitly cost out which of the three alternatives should be used at lower levels of repair, i.e., the shop replaceable unit (SRU) level, the module level, and the piece-part level. Instead, either an average or a maximum cost of the three alternatives at each of these lower levels is assumed to be known.

About 90 percent of all level of repair models currently in the literature fall into this category. Some of the more notable among these are:

1'. The Air Force Optimum Repair Level Analysis (ORLA) model as defined in AFLC/AFSC Manual 800-4. Various versions of this model have been used in several recent Air Force acquisition programs including the F-15 aircraft. In each of these cases, the model has been provided to the contractor as a minimum acceptable basis for determination of a repair level policy, and the contractor has been encouraged to extend and/or improve the model to more accurately reflect peculiar properties of the particular equipment being considered.

2'. The Navy Level of Repair Model as defined in Military Standard 1390.

3'. The McDonnell Douglas Level of Repair Model.

B. SINGLE ITEM - MULTI INDENTURE MODELS

Like the single item-single indenture model, this type of model costs out the discard at failure, repair at base, and repair at depot maintenance alternatives for a given line replaceable unit. But unlike the single indenture type of model, it also explicitly

costs out each of the three maintenance policies at the SRU, module, and piece-part level.

This type of model shares the first limitation described above, i.e., it requires several iterations when costs of support and test equipment used on several LRUs are involved. It usually uses an optimization procedure such as dynamic programming to cost out each maintenance alternative. Three models belonging to this category are the General Dynamics SG-8 Model, the Hughes Cost of Ownership Model (HCOM), and the Naval Air Development Center Level of Repair Analysis Model for Engines. The Navy model determines the optimum set of repair levels using exhaustive enumeration.

C. SYSTEMS MODELS

The systems approach costs out maintenance alternatives at the subsystem level, i.e., one level of indenture higher than the first two approaches. Hence, it is more comprehensive than these approaches in that it more accurately considers the optimum sequence of maintenance actions necessary to correct a failure and return the subsystem to serviceable condition. In addition, it avoids the problem of allocating costs of support equipment used on different LRUs of a given subsystem.

The primary limitation of the systems approach is its extensive requirement for input data. It also has the cost allocation problem in cases where support or test equipment is used on more than one subsystem.

A prime example of the systems approach is the Air Force Range Model (RGM). This model uses dynamic programming to calculate the combination of repair procedures for the total subsystem that will minimize support costs. To date, it has not been implemented in total on a major acquisition program, largely because of its extensive input data requirements.

VI. MAINTENANCE MANPOWER PLANNING MODELS

Maintenance manpower requirements clearly have a significant impact on the costs of maintaining most Air Force equipments. Mathematical models can be used as an aid in making two types of maintenance manpower decisions: (1) in evaluating the effects of alternative equipment designs on maintenance manpower requirements and (2) in evaluating the impact on cost of alternative maintenance policies. Careful use of these models can bring about substantial reductions in life cycle cost.

The model described below utilizes simulation to estimate maintenance manpower requirements. Simulation is a numerical technique for conducting experiments on a digital computer with a mathematical model that describes the behavior of a system over extended periods of time.

A SIMULATION MODEL FOR ESTIMATING MAINTENANCE MANPOWER REQUIREMENTS*

Objective of the Model: To provide an improved method for:

1. Estimating the maintenance manpower requirements of a weapc system under development.

2. Evaluating design tradeoffs for a weapon system under development on the basis of maintenance manpower requirements.

3. Comparing alternative weapon systems being considered for acquisition on the basis of maintenance manpower requirements.

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* Further information about this model is available from Major D. C. Tetmeyer, ASD/ENC, Wright-Patterson AFB, Ohio 45433 or Mr. F. A. Maher, AFHRL/ASR, Wright-Patterson AFB, Ohio 45433 (513/255-3871)

4. Evaluating maintenance manning policies for weapon systems currently in the Air Force inventory.

Description of the Model:** The model simulates the function of flying a given set of aircraft, the function of maintaining this set of aircraft, and the interaction between these two functions. The functions are described to the model by parameters specified by the user. These inputs include:

1. Data that describe the weapon system, e.g., unit cost, failure rates of subsystems and components, types of AGE required by the system, etc.

2. Data that describe the maintenance plan, i.e., class of maintenance (e.g., unscheduled, scheduled, or phase), type of maintenance (e.g., trouble-shoot), and resource requirements (e.g., maintenance crew size, task times, and required manning specialties and skill levels.

3. Data that describe the mission, e.g., mission type, sortie length, priority, aircraft type, fleet size, lead times, delay times, launch times, and spares availability.

The aircraft operations and support requirements, and demands on aircraft imposed by the flight schedule interact with one another in the model. The model "flies" airplanes according to the mission

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** This model is divided into a series of modules, the main one of which is the LCOM (Logistics Composite) Model, developed by the RAND Corporation for AFLC.

schedule. As the schedule dictates, the model draws on the aircraft pool and processes appropriate numbers of aircraft (if available) through the presortie tasks (with the lead time for presortie processing determined by the user). Given that presortie tasks are completed in time to meet the mission schedule, the model "flies" the sortie. Concurrent with the accomplishment of the sortie, subsystem and component failure clocks are decremented (where these failure mechanisms are expressed in terms of "mean sorties between maintenance actions"). When the aircraft lands, it receives a basic postflight or turnaround postflight according to the operations schedule, and the model checks the clock values to determine if any failures have occurred. When unscheduled maintenance is performed, the model calls upon the various resource pools (manpower, spares, and AGE) to repair the malfunction. If the resources prescribed for this task are depleted or devoted to another task, the aircraft must wait (where, depending on the priorities assigned by the user, one task may preempt another and the resources directed to the higher priority task). After the failed equipment is repaired, the aircraft is returned to the pool and becomes available for flying again if called for by the mission schedule. Failed components that are removed from the aircraft during unscheduled maintenance are channelled into the shop where they may be repaired or processed for NRTS (not reparable this station) shipment to the depot. Either of these actions will eventually result in the return of the component to the spares pool.

The output format of the model reflects the interaction among support resources and their relationship to operational capability. It has two parts: (1) a Performance Summary Report which provides detailed information on the level of operation achieved during the simulation, and on the use and expenditure of resources necessary to sustain that level, and (2) a work center matrix which graphically depicts the number of personnel that must be available in a work center in order to meet "on aircraft" demands for maintenance over the span of time represented in the model. The model can be run repeatedly, each time with differing mission requirements. The set of differing manning requirements that result from these runs can then be input as data points to a regression program which calculates equations that reflect optimal work center manning for all appropriate points in the operations spectrum. These equations, in turn, serve as inputs to a Manpower Program which generates a manpower document (Basic Authorization) for any given flying hour program.

Since the model is modular in structure, portions of it can be used for other purposes. For example, the impact of different design alternatives on manpower can be determined using the Performance Summary Report. This tool may be helpful in determining optimal mixes of manpower, spares, and AGE resources.

Recent Experience with the Model: This model has been successfully implemented in several Air Force programs so far and prospects for future use are good. It has been used:

1. To estimate maintenance manning requirements during the prototype development phase of the A-X Program.

2. To analyze the effects of design alternatives on maintenance manning in the A-10 Program.

3. To compare the maintenance manning requirements of the A-10 and A-7 during the recent A-10 - A-7 flyoff.

The model is currently being used by TAC to evaluate maintenance manning policies for several aircraft currently in the inventory. It is one of the central tools being used in the current effort to incorporate a life cycle cost estimating capability in DAIS (Digital Avionics Information System). Also, decisions have been made to use the model to compute maintenance manning requirements for the Air Combat Fighter and to experiment with the model in the B-1 Program.

VII. INVENTORY MANAGEMENT MODELS

A significant reduction in the life cycle cost of a system can often be achieved by reducing the number of spare items required to keep the system operational. To a large extent, this can be achieved by better management of spares inventories.

During the past several years, a considerable number of mathematical models that treat various aspects of managing inventory systems have been developed. One of these models, called METRIC (Multi-Echelon-Technique-for-Recoverable-Item-Control), was specifically designed for the Air Force at the RAND Corporation. It is a method for determining optimal stock levels in a two-echelon, base and depot, inventory system for recoverable, i.e., reparable, items. Recoverable items are typically very expensive and their replacement demand rates are relatively low. However, it is important that they be managed properly since about 65 percent of the Air Force's total investment in spares is concentrated in these items.

The section below describes an extension of METRIC called MOD-METRIC. This model determines an optimal allocation of spare items for a system that can result in a considerable reduction in spares investment necessary to keep the system operational.

MOD-METRIC

MOD-METRIC is an acronym for a mathematical model developed at Hq AFLC for the control of a multi-item, multi-echelon, multi-indenture inventory system for recoverable items, that is, items

subject to repair when they fail. The objectives of the model are to describe the logistics relationship between an assembly and its subassemblies, and to compute spare stock levels for all echelons (e.g., base, intermediate, and depot level shops) for the assembly and subassemblies with explicit consideration of this logistics relationship.* In particular, the model is used to determine spare stock levels at each echelon which minimize total expected base backorders for the assembly subject to a constraint on investment in spares. By changing the level of this constraint and solving the model repeatedly, a curve of minimum expected base backorders achievable versus dollars spent on spares can be derived for use in determining an appropriate level of investment for spares.

Required inputs to MOD-METRIC include frequency of removals of each subassembly, average resupply times, not reparable this station (NRTS) rates, average repair time at each echelon, etc. In other words, a well defined maintenance concept is required by the model so that its usefulness for conceptual phase analysis is limited. However, the model can be used effectively once design options are defined, to determine the impact of alternative maintenance concepts on spares requirements.

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* The logistics relationship is described in the model by an equation. This equation reflects the average resupply time of the assembly as a function of (1) the probabilities that a given assembly failure was isolated to each of the components comprising the assembly and (2) the average resupply time for each of these components.

MOD-METRIC has been implemented by the Air Force as a method for computing spare stock levels for the F-15. The B-1 SPO expects to use it; and the A-10 Program, the AWACS Program, and the space shuttle program are considering using it. There exists an AFLC pamphlet, AFLCP 57-13, which provides detailed instruction on using the AFLC CREATE system to access and use MOD-METRIC computer programs. These instructions may be used by personnel who perform analysis of resource allocation or are authorized to use MOD-METRIC to compute requirements.*

* An article describing the MOD-METRIC technique, entitled "A Model for a Multi-Item, Multi-Echelon, Multi-Indenture Inventory System" by Major John A. Muckstadt, Hq AFLC, Wright-Patterson AFB, Ohio can be found in Management Science, Volume 20, No. 4, December 1973, Part I.

VIII. WARRANTY MODELS

In recent months, the Air Force has been seriously examining the pros and cons of a more widespread use of reliability improvement warranties (RIW) in the acquisition of new weapons systems/equipments. Recent studies have concluded that a properly constituted and applied warranty can yield significant reliability and LCC benefits. The Director, Procurement Policy, Hq USAF, has recently published a set of interim general guidelines with respect to RIW application criteria, funding of RIWs, essential elements to be included in an RIW contract clause, determination of the cost-effectiveness of an RIW provision, and evaluation approaches for assessing the cost-effectiveness of an RIW after it has been implemented. It should be noted, however, that these guidelines provide no specific cost methodology to be used in determining cost-effectiveness. In order to bridge this gap, the Government must develop models that will compute parameters for aiding in making warranty-related decisions, e.g., optimal warranty time period, break-even costs, etc. One such model is described on the following pages.

AN LCC MODEL FOR USE IN NEGOTIATING RELIABILITY IMPROVEMENT WARRANTIES*

Objective of Model: This model evaluates the life cycle costs associated with a reliability improvement warranty (RIW) provision

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* Use of Warranties for Defense Avionic Procurement, ARINC Research Corporation, sponsored by Defense Advanced Research Projects Agency, ARPA Order No. 2360, also Final Technical Report No. RADC-TR-73-249, June 1973. The monitors for this contract were Mr. Russell Shorey, ODDR&E, The Pentagon, Washington, D.C. 20330, and Mr. A. Feduccia, RADC/RBRS, Griffiss AFB, New York 13440.

in the procurement of defense avionic equipment. The model computes:

1. Savings achievable by using a warranty as a function of length of warranty period in order to determine an optimum warranty period length.

2. The break-even or "indifference" price for items purchased under a warranty provision as a function of length of warranty period, i.e., that price whereby the expected total user cost under warranty is equal to the total cost that the user would expect to incur without a warranty.

The model is developed to be applicable during the development and preproduction stages when consideration of a warranty provision for the production contract is most important.

Model Description: The model considers three cost elements for any given equipment procurement: initial acquisition costs, direct costs associated with failures, and indirect costs associated with maintenance support. In simplified form, the model can be stated as follows:

> Life Cycle Cost over (0,T) = Number of units purchased x purchase price per unit + expected number of failures over (0,T) x cost per failure + maintenance support costs over (0,T).

The detailed form of the equation above depends on whether it is being formulated to reflect a warranty or a no-warranty situation. Except for direct reliability modification cost, the model assumes that the user incurs the same kinds of costs in the warranty case as in the no-warranty case. Clearly, his in-house direct maintenance

costs will be less in the warranty case. His initial support costs will also be less, especially if his equipment is new to the inventory. However, there will be additional costs for warranty administration. The model assumes that all costs expected to be incurred by the contractor in the warranty case are included in the contract price, burdened by fee and risk factors.

Examples of Model Use and Prospects for More Extensive Use: To date, the RIW LCC model has not been used in a real world procurement because (1) it is very complex and hence, difficult to understand, and (2) several of its assumptions regarding failure rates, effectiveness of modifications, etc., have not been sufficiently validated.

In late spring of 1974, a follow-on contract with the objective of making the model workable and useful as a decision tool was awarded.* Some of the contract's specific goals are:

1. To determine if the objectives of the model in the way it computes LCC in the no-warranty case are consistent with the objectives of the more traditional models that have been used to estimate LCC in recent procurements.

2. To more fully develop the concept of reliability growth during the warranty period in the model.

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* The monitor for this contract is Mr. Gene Fiorentino, RADC/RBRS, Griffiss AFB, New York 13440.

3. To implement the model on an experimental basis in some future procurements, e.g., the ARN-XXX TACAN currently in development.

4. To determine the sensitivity of the model to labor rates and to examine the model's assumptions about labor rates.

5. To test the validity of the probability distribution used by the model to reflect the frequency of equipment modifications.

This study is scheduled for completion in June 1975. Hopefully, it will provide solutions to many of the problems that now plague warranty models, so that models of this kind will soon be an effective aid when deciding whether or not a warranty should be used, how much it should cost, and what the warranty period should be.

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